SDA: Software-Defined Accelerator for general-purpose big data analysis system

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Baidu 百度

Baidu is beyond a search engine

- Search

- O2O/autonomous car/cloud/finance…

Bai du 百度

Outline

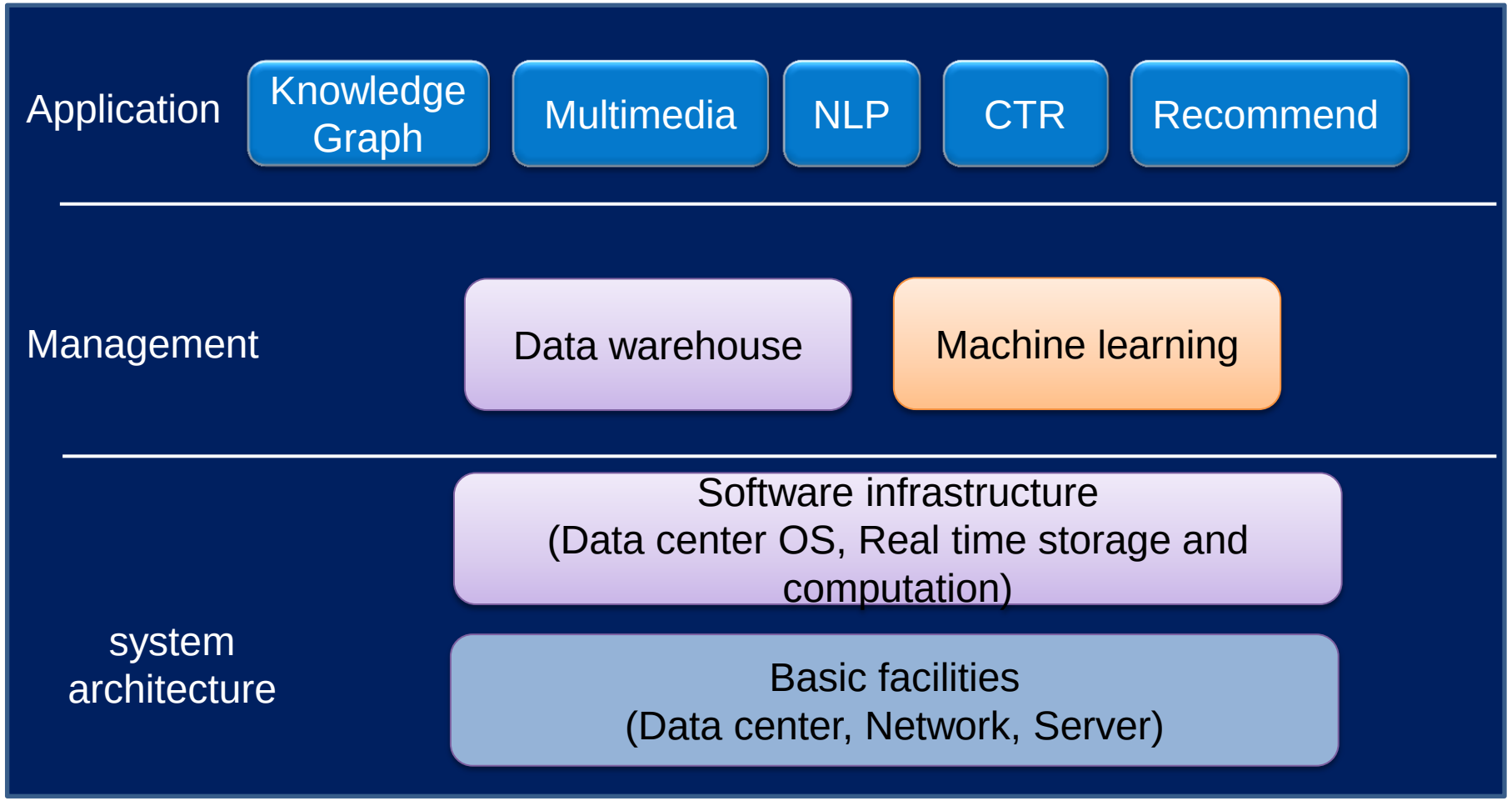
- The overview of big data and its system
- Motivations and challenge of accelerating big data processing
- Our solution : SDA for big data
  - Design goals
  - Design and implementation
  - Performance evaluation
- Conclusion

The overview of big data and its system

Total data:	~1EB
Processing data :	~100PB/day
Total web pages:	~1000 Billion
Web pages updated:	~10Billion/day
Requests:	~10Billion/day
Total logs :	~100PB
Logs updated:	~1PB/day

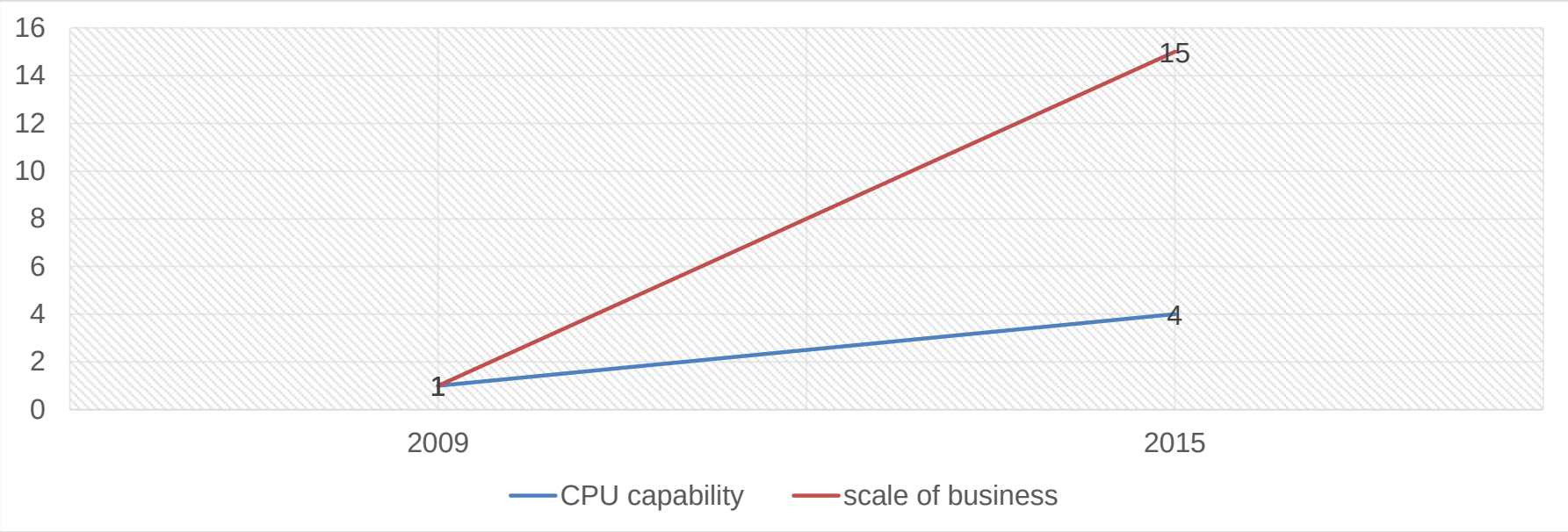
Data is big

The overview of big data and its system



- Applications are diverse
- Systems are complex

Motivation of accelerating big data processing



- CPU typical configuration in data center
  - 2009, dual-core, ~3.0Ghz
  - 2015, 8-core, ~2.0Ghz
- Scale of business (Baidu revenue)
  - 2009, ~4.4B RMB
  - 2015,~66B RMB

- Computing = data scale * algorithm complexity
- Trends
  - Data scale increase rapidly
  - Algorithm complexity increase rapidly
  - Performance of CPU increase slowly
- Need to bridge the gap

Challenges of accelerating general-purpose big data processing

- Difficult to abstract the computing kernels
  - Diversities of big data applications
  - Variable computing type

- Difficult to be integrated into distributed system
  - Variable platforms and program models
    - MR
    - Spark
    - Streaming
    - User defined
  - Variable data type and storage format

Our solution : SDA – Software-Defined Accelerator

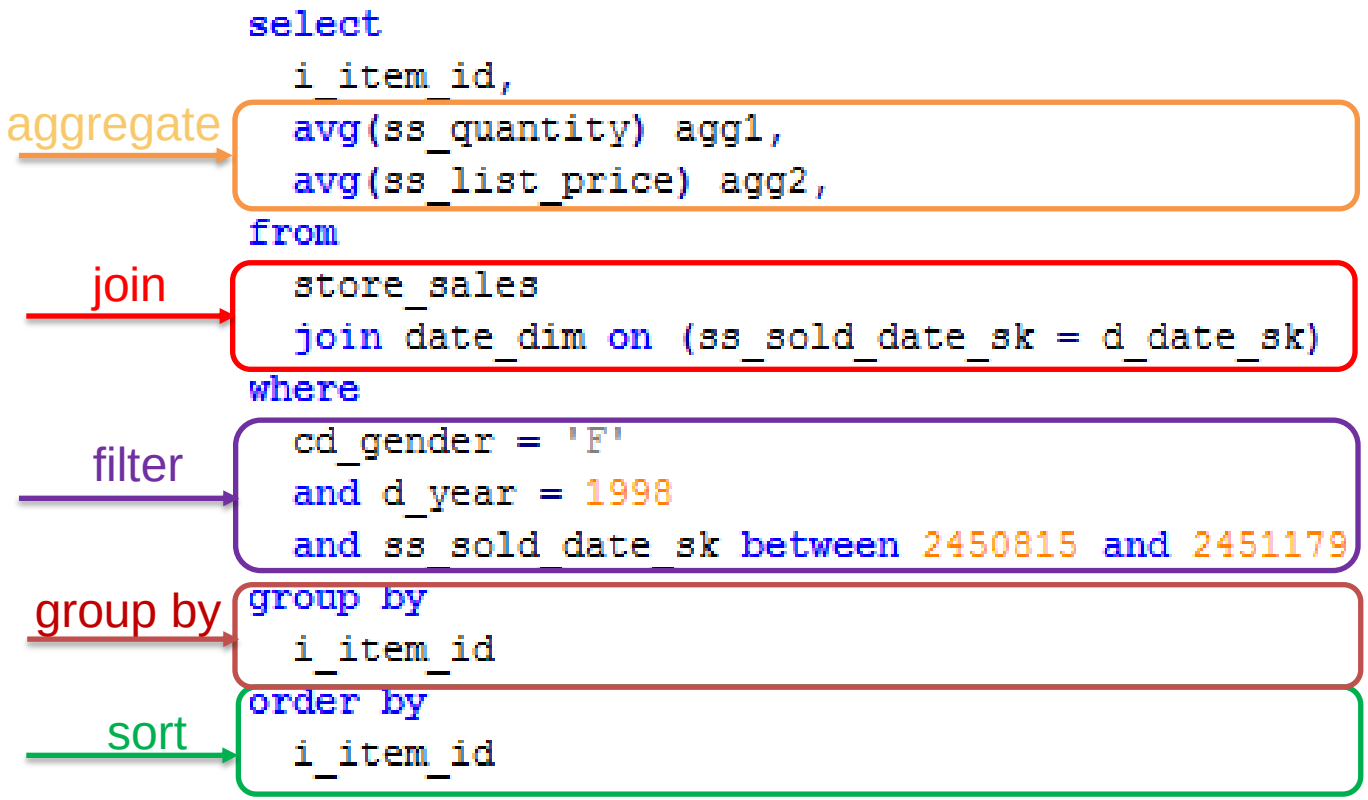
- Our observations
  - ~40% data analysis jobs written in SQL
  - Most others of data analysis jobs can be rewritten in SQL
  - Lots of popular SQL system
    - HIVE
    - Spark SQL
    - Impala…
- our solution
  - Software-Defined Accelerator for data analysis system

SDA – design goal

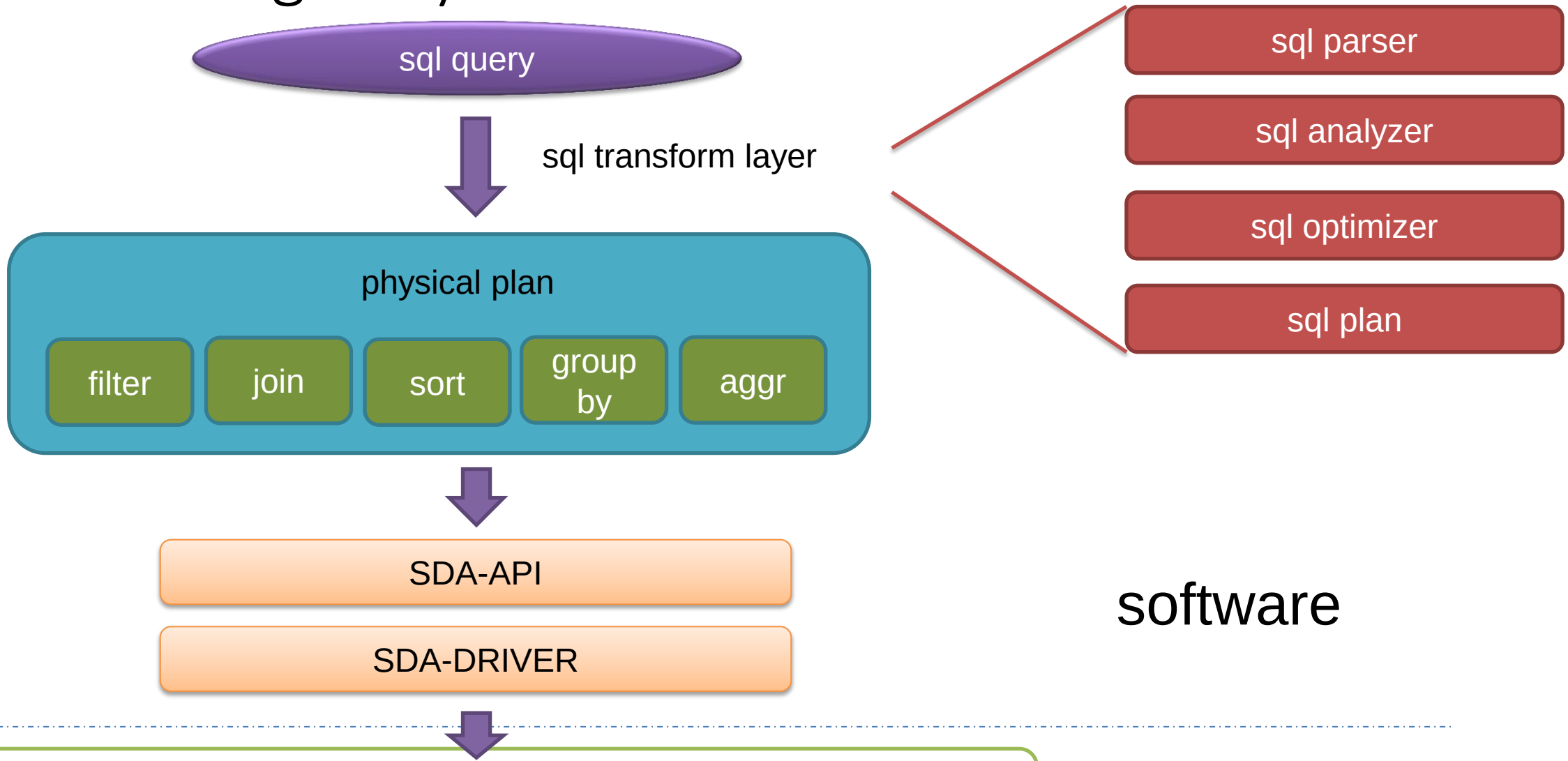
- Focus on general purpose data analysis system
  - SQL accelerator
    - Hiding the diversities of big data workloads
- Can be easily integrated into distributed system
  - For example, Spark SQL

SDA design – abstraction of SQL kernels

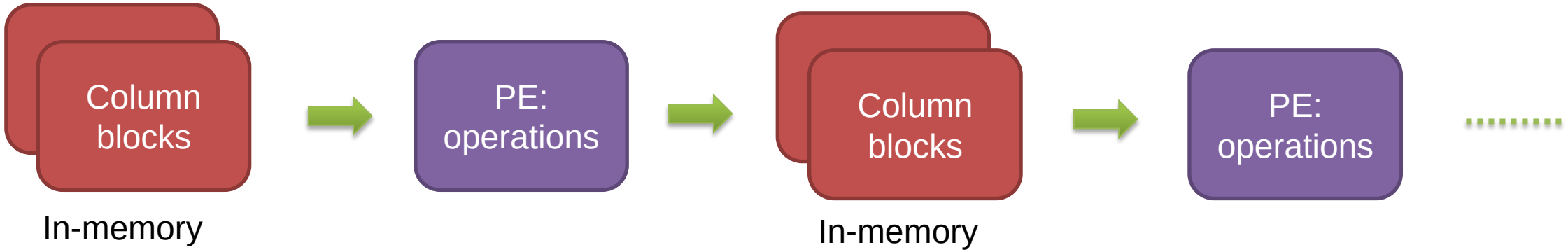
- Operations abstraction
  - Filter
  - Sort
  - Aggregate
  - Join
  - Group by
- Data type
  - Char/uchar/short/ushort
  - Int/uint/long/ulong
  - Float/double(time)
  - string



SDA design - system



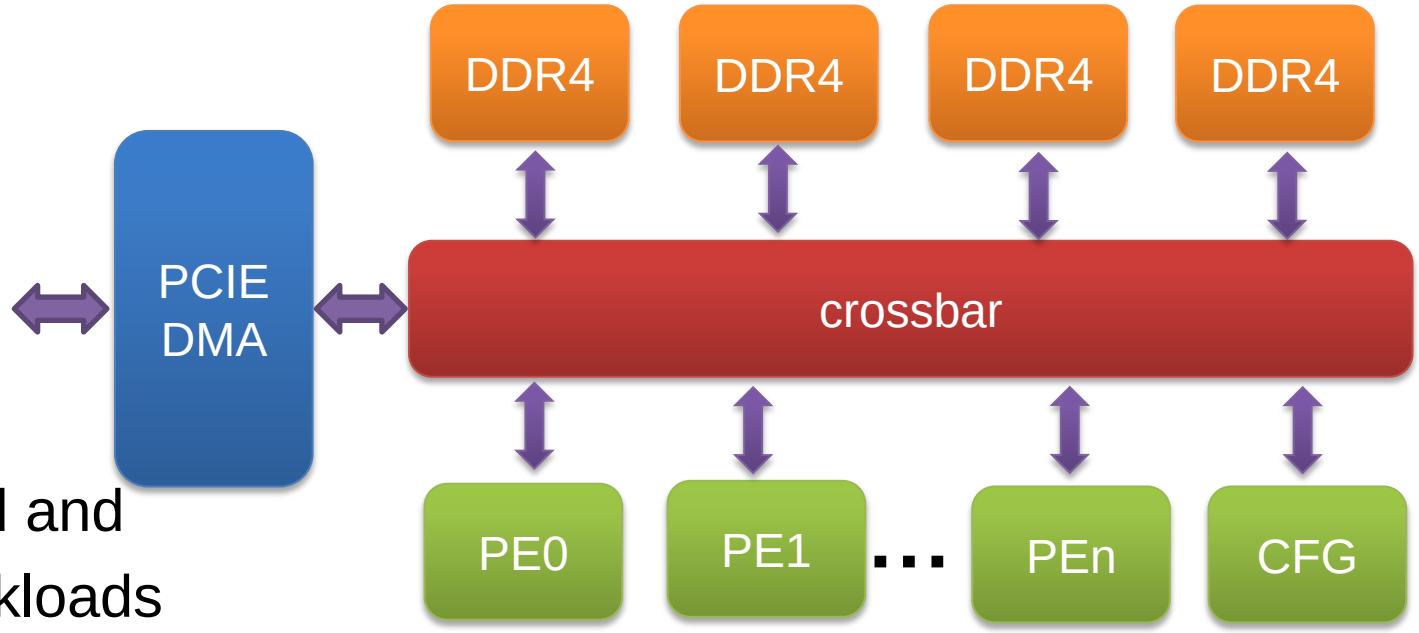
SDA design– data flow program model



- Data blocks resident in on-board DDR memory
  - Column store
  - Reduce communication overhead
- Copy block to host
  - The operations which are not supported by SDA
  - Shuffle operation

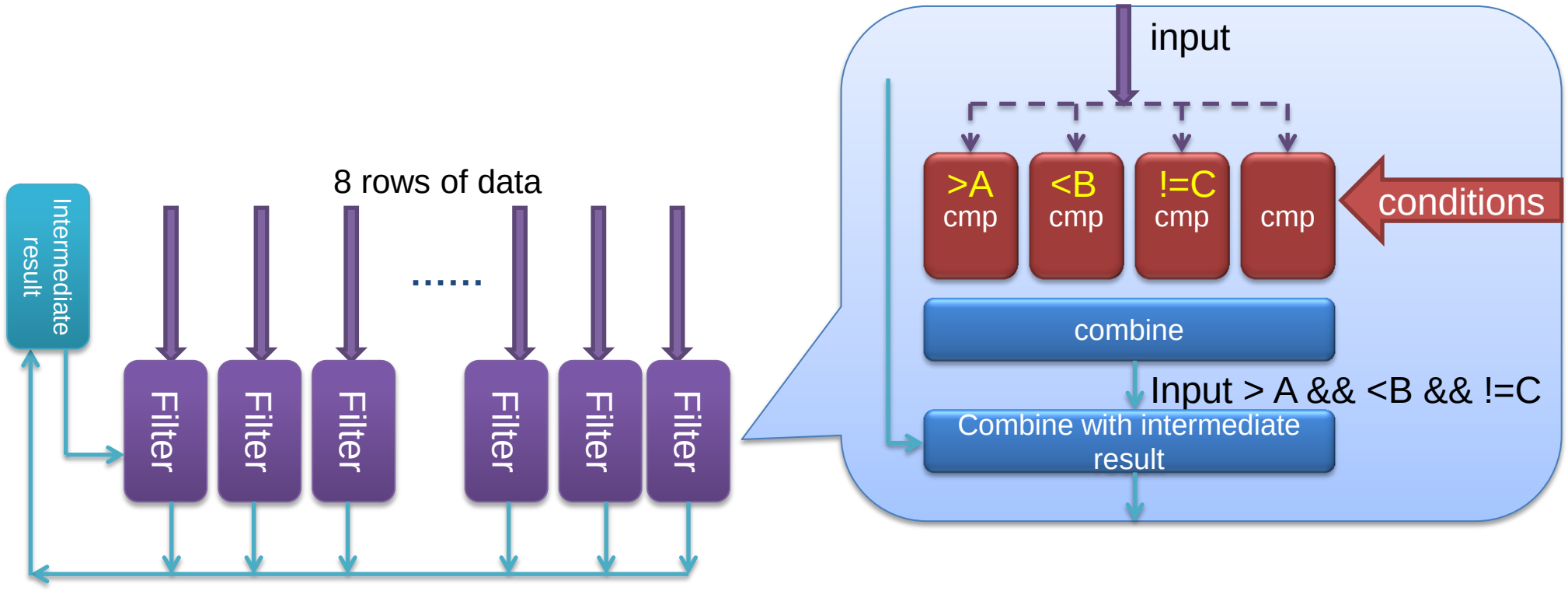
SDA design– hardware

- PE(processing element)-based architecture
  - Scalable
  - Flexible
- Dynamic re-configurable
  - Resource on-demand
  - Dynamically configure the kind and Number of PEs according to workloads
- PE
  - Single operation: filter/sort/join…
  - Support variable data type



SDA design: filter PE micro-architecture

- Represent Filter conditions by postfix expression
- Highly parallel data path



SDA Implementation - hardware board

- Full-height, half-length
  - Feasibility for large-scale deployment
- Xilinx KU115 FPGA
- ~50W total power
- 4 x 72bit DDR4, 2400MHz
  - 8GB ~ 32GB capacity
  - ~76GB/s bandwidth with ECC
  - Big data applications are memory bandwidth bound
- PCI-e 3.0 x 8 lanes

SDA implementation – FPGA logic

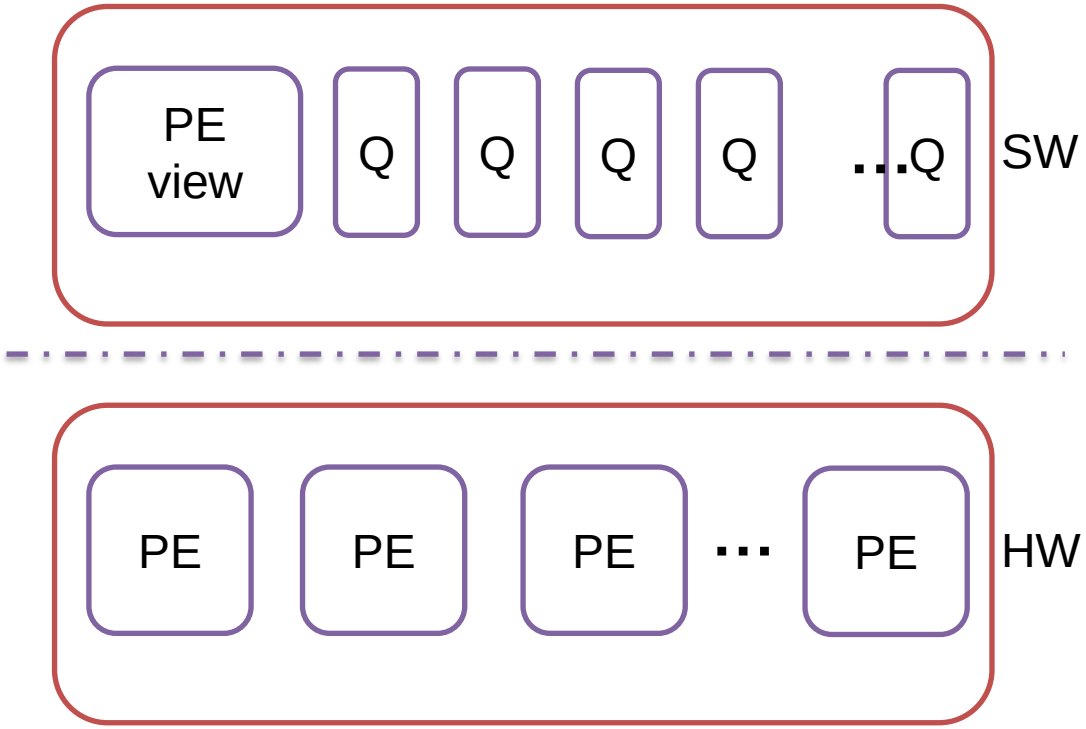
- Running at 300MHz

- RTL flow

Function	LUT	BRAM	DSP
Filter	16k (2.5%)	67 (3%)	3 (~0%)
Sort	85k (12.8%)	331(15%)	150(2.7%)
Aggregate	11k (1.6%)	56 (2.5%)	20 (~0%)
Join	15k (2.4%)	600(27%)	0
Group by	95k (14%)	380(17%)	170(3%)

SDA implementation – integration with distributed system

- Driver
  - Configure PEs according to workload
  - Allocate Queues for PE
  - Maintain the views of PE



- APIs
  - C++ library

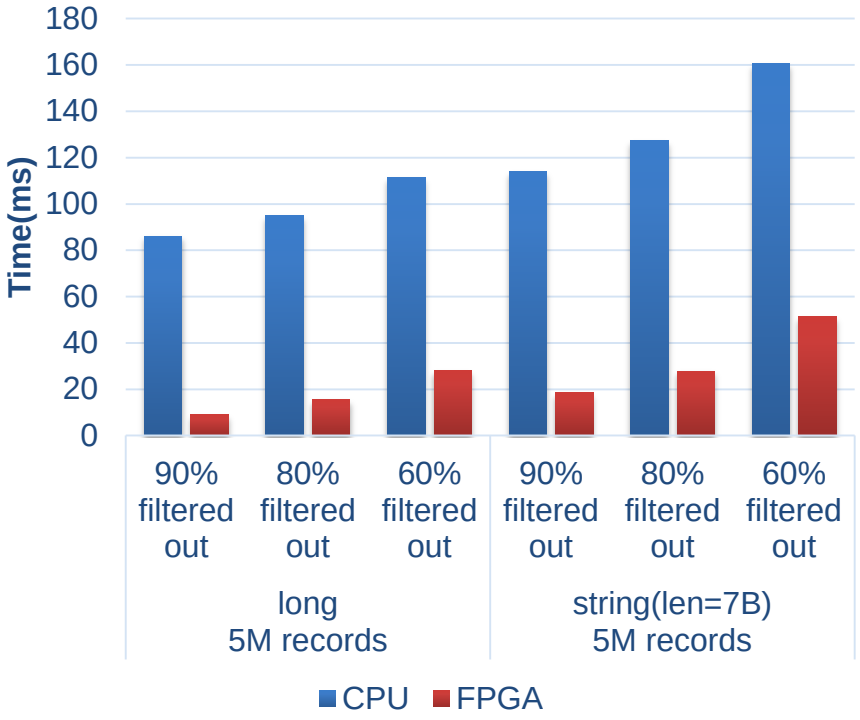
```
bool filter(int fd,
    __in const column* columns, uint8_t col_count,
    __out column* results, uint8_t ret_col_count,
    const op_info* expr, uint8_t op_count);

bool sort(int fd,
    __in const column* columns, uint8_t col_count, uint8_t j, bool descend,
    __out column* results, uint8_t ret_col_count);
```

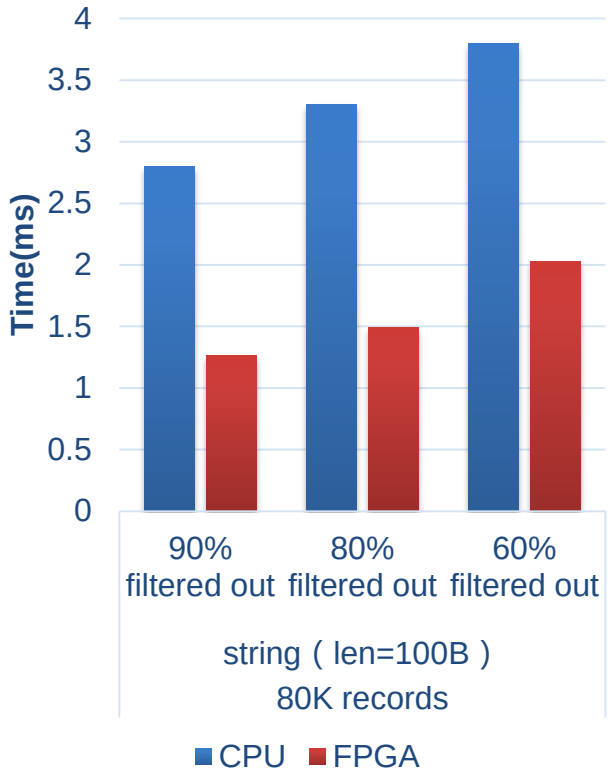
Evaluation

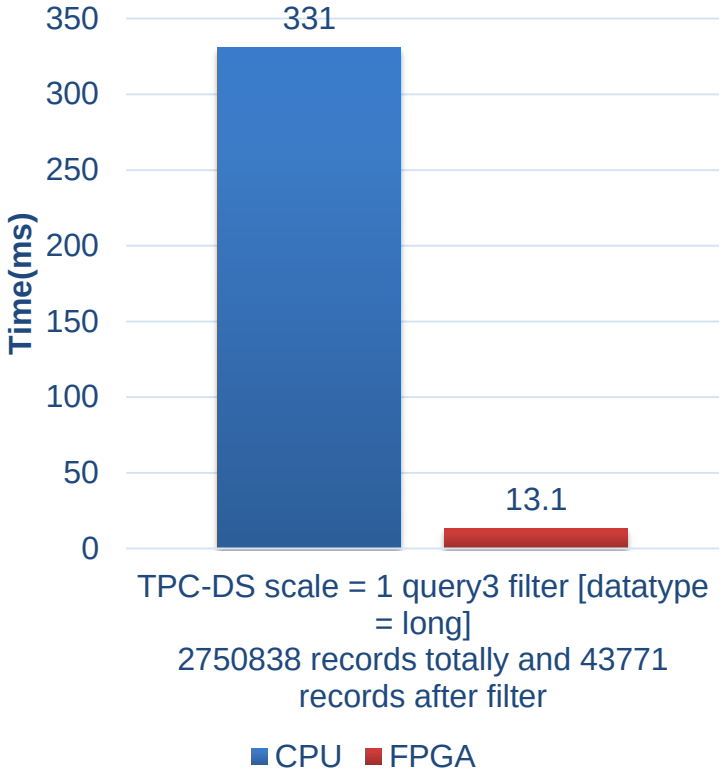
- Setup
  - Host
    - Intel E2620 x2, 2.0Ghz, 12 cores
    - 128GB memory
    - Linux
  - SDA
    - 5 PEs: filter, sort, aggregate, join, group by
    - 300MHz

Evaluation - filter

- Micro benchmark
  - At most 10x than dedicated C++ comparator
- Real case: TPC-DS query3
  - 25x faster than general C++ comparator

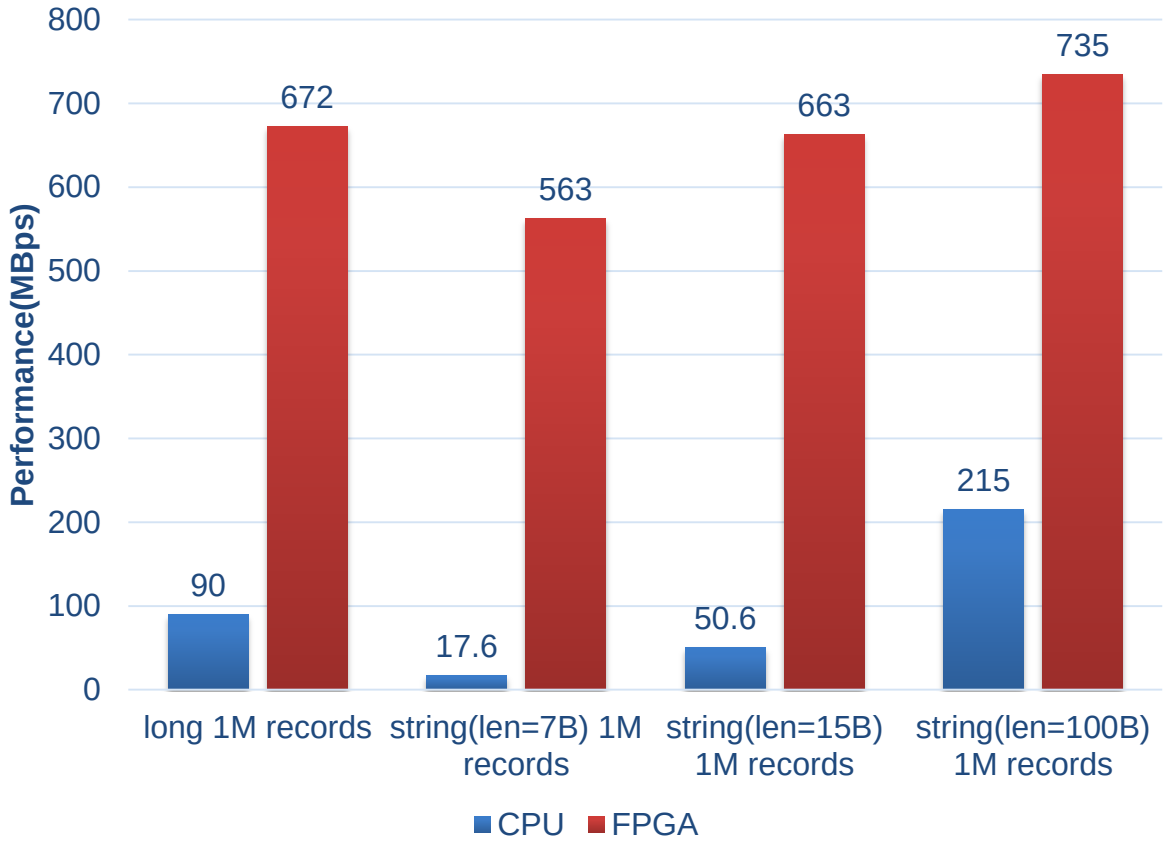




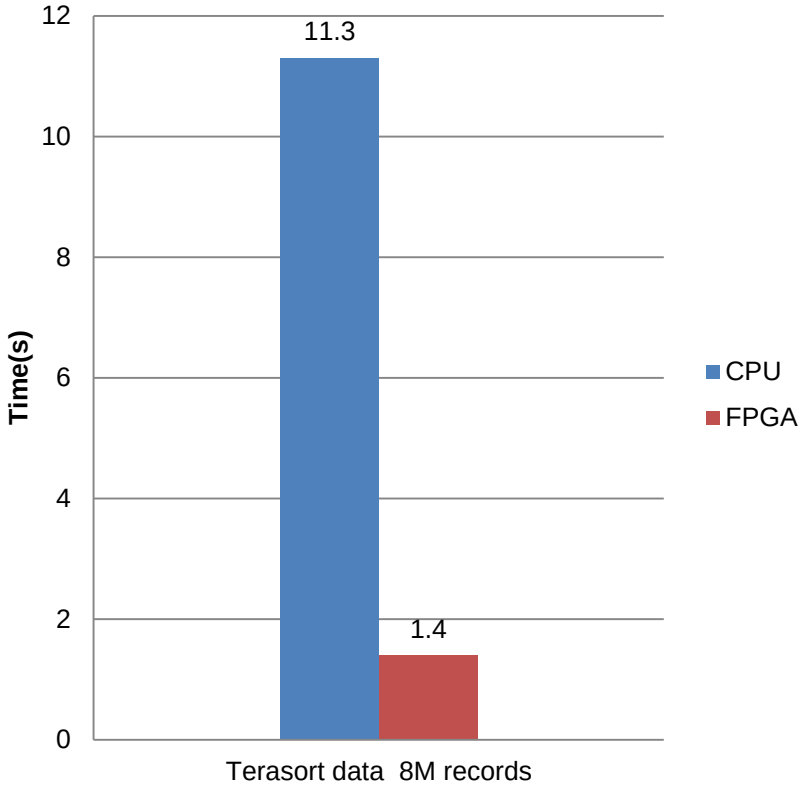


Evaluation-sort

- Micro benchmark
  - At most 33x

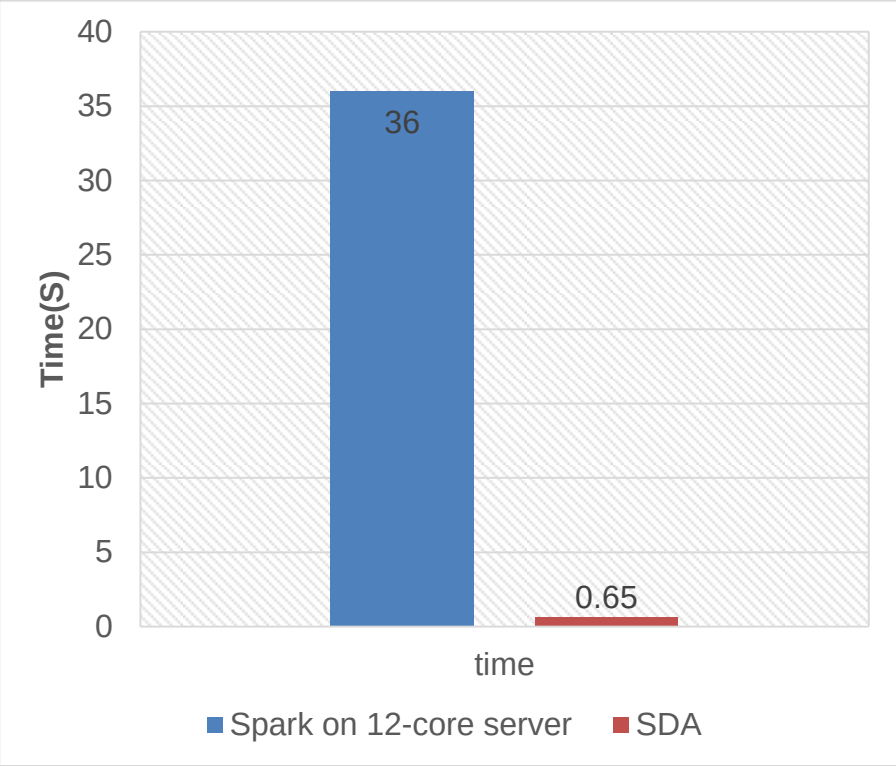


- Terasort
  - 8x



Evaluation - real case query

- TPC-DS scale = 10， query3
- Execution time
  - 55x




```
select
  dt.d_year,
  item.i_brand_id brand_id,
  item.i_brand brand,
  sum(ss_ext_sales_price) sum_agg
from
  store_sales
  join item on (store_sales.ss_item_sk = item.i_item_sk)
  join date_dim dt on (dt.d_date_sk = store_sales.ss_sold_date_sk)
where
  item.i_manufact_id = 436
  and dt.d_moy = 12
  and (ss_sold_date_sk between 2451149 and 2451179
    or ss_sold_date_sk between 2451514 and 2451544
    or ss_sold_date_sk between 2451880 and 2451910
    or ss_sold_date_sk between 2452245 and 2452275
    or ss_sold_date_sk between 2452610 and 2452640)
group by
  d_year,
  item.i_brand,
  item.i_brand_id
order by
  d_year,
  sum_agg desc,
  brand_id
limit 100
```

Related work

- Sorting
  - GTX Titan : ~500M int64 on 1M inputs (https://nvlabs.github.io/moderngpu/mergesort.html)
  - SDA: 84M int64 of one PE, 336 M of 4 PEs
  - SDA is ~4x power efficiency than GPU

- GPU/FPGA accelerator for SQL kernels
  - Lots of papers and some startups
    - Only support a subset of data type and operation
  - No work on whole TPC-DS query
    - GPU is not good at complex data type, such as variable length string
    - Most keys of real workload are variable length string, such as city, people and item

- Advantages of SDA
  - Support all data type of TPC-DS
  - General-purpose, support most operations of TPC-DS
  - High performance benefited from
    - Random memory access
    - Data locality
    - Customized pipeline and ALU

Conclusion

- Firstly present general-purpose big data accelerator
  - Abstract SQL operations
  - Propose the SDA hardware and software architecture
  - Implement SDA hardware by FPGA
- SDA is also designed for distributed system
  - Data flow program model
  - Resource on-demand
- Demonstrate the feasibility of SDA for big data and AI
  - SDA for AI on Hotchips 2014